TECHNICAL PUBLICATION

Reducing NO_X Emissions and Commissioning Time on Southern Company Coal Fired Boilers With Low NO_X Burners and CFD Analysis

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ABSTRACT

Riley Power Inc. (RPI), a subsidiary of Babcock Power Inc. has successfully retrofitted two different types of Southern Company utility boilers with low NO_X dual air zone burners. The first type is a 115 MWg, front wall fired, sub-critical boiler while the second type is a 535 MWg, two-high-cell opposed-fired, supercritical boiler. The low NO_X burners in both boiler types feature CCV® coal nozzles and low swirl coal spreaders in conjunction with the latest flame stabilizer ring technology which provides enhanced NO_X reduction. The objective of these projects was to reduce NO_X emissions significantly without the use of overfire air (OFA) or burner re-spacing while firing a wide variety of eastern bituminous coals and maintaining boiler performance as determined during pre-retrofit operation. To minimize startup, commissioning and optimizing time (and costs), computational fluid dynamics (CFD) modeling was used to determine initial low NO_X burner settings for optimum NO_X performance.

Performance guarantees for NO_X emissions, CO emissions, and unburned carbon (UBC) in fly ash along with reheat temperature, superheat steam temperature and boiler efficiency were all achieved. For both boiler types, the NO_X emissions were reduced more than 60% from uncontrolled levels using a "burners only" approach. These two boilers, with different designs and firing arrangements, represent some of the lowest NO_X levels achieved in the industry without the need for OFA. Commissioning of the burners was reduced from a typical low NO_X burner installation by approximately 50 percent. This paper describes the results from these low NO_X burner retrofit projects including boiler performance data prior to installation of burners and post-retrofit data after installation of the low NO_X burners.

INTRODUCTION

RPI developed the Combustion Controlled Venturi (CCV®) burner in the early 1980s to lower NO_X emissions from pulverized coal fired utility boilers. The CCV® burner design has evolved throughout the years, and the latest Dual Air Zone CCV® Burner is capable of achieving significant NO_X reductions in various types of applications, new and retrofit[1]. To date, RPI has provided over 1,800 low NO_X CCV® Burners to the power industry with a total electric generating capacity of nearly 22,000 MW.

Figure 1 shows the latest Dual Air Zone CCV® burner design for reducing NO_X emissions from fossil-fired utility and industrial boilers. Pulverized coal is the primary fuel burned using this design. However, with the proper equipment installed for dual fuel firing capability, oil and/or natural gas can also be fired. The patented venturi coal nozzle, low swirl coal spreader, and flame stabilizer ring in the Dual Air Zone CCV® burner results in a well attached fuel rich flame core, the fundamental condition necessary for minimizing the formation of both fuel and thermal NO_X.

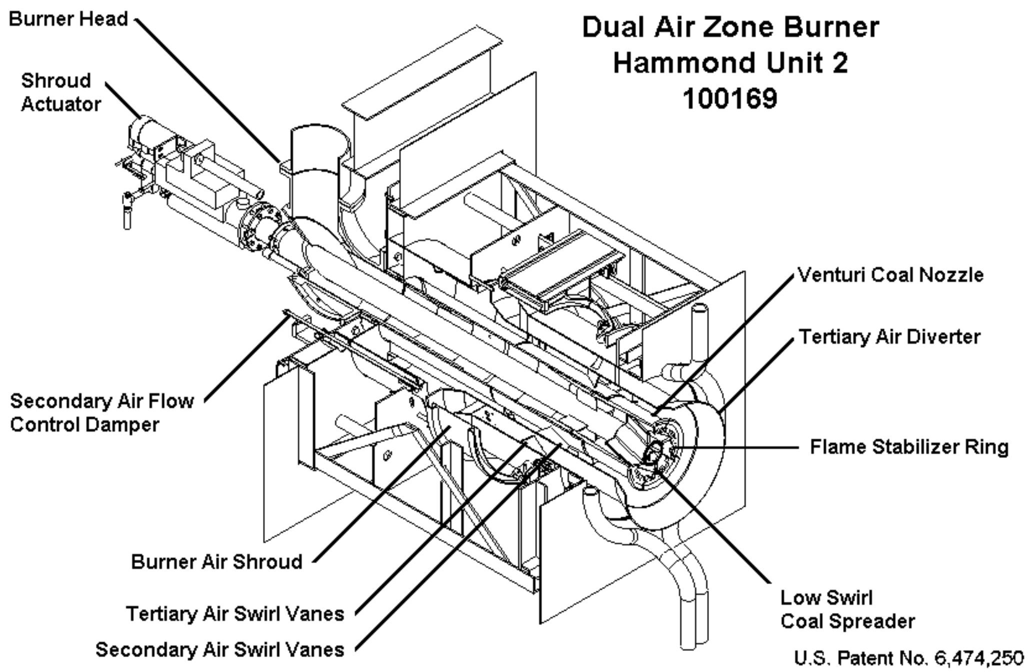


Figure 1 Typical low NO_X Dual Air Zone Burner

Total combustion air flow to the Dual Air Zone CCV® burner is controlled by an automated air shroud that surrounds the burner air register. The air entering the register is divided into secondary air (SA) and tertiary air (TA) streams by a manual SA flow control damper. The register also features fixed SA swirl vanes and manually adjustable TA swirl vanes. The register design provides independent control of total air flow, SA/TA flow split, and TA swirl. The burner air flow is measured using individual burner air flow probes, supplied by Air Monitor Corporation, for secondary and tertiary air[2]. The ability to control internal burner air staging with the Dual Air Zone CCV® burner makes it possible to control NO_X formation rate.

Start-up and optimization of any low NO_X burner retrofit can be time consuming and can involve many adjustments. To minimize this process RPI utilized Computational Fluid Dynamics (CFD) to model the CCV® Dual Air Zone burner. These models greatly improve RPI's ability to initially adjust the burners to provide proper swirl and air flow splits, thereby decreasing the amount of time required for parametric testing. RPI's low NO_X burner design utilizes Air Monitor Corporation's Individual Burner Air Measurement (IBAM™) probes to measure the air flows in the secondary and tertiary air passages[2]. The combination of these systems allowed for the start-up and optimization of the low NO_X burners to be completed in relatively short time duration.

As a result of the State of Georgia's efforts to reduce ozone in the Atlanta ozone nonattainement area, Georgia Power (a subsidiary of Southern Company) is required to make significant reductions in NO_X emissions during the ozone season (May-September, beginning in 2003) from seven plants in the northern part of Georgia. RPI was contracted by Southern Company to retrofit Hammond Units 1, 2 and 3, and Branch Units 3 and 4 with low NO_X Dual Air Zone CCV® coal burners. The Hammond units feature a front wall fired furnace while the Branch units feature an opposed cell-fired furnace. To date, burner performance optimization and acceptance tests have been successfully completed on Hammond Units 1 and 2 and Branch 4 with all performance guarantees being met. This paper presents results of burner performance tests at these Georgia Power plants along with technical details of the project. The use of CFD modeling on both of these low NO_X burner retrofit projects is described in detail, presenting the benefits of CFD modeling with examples.

HAMMOND UNITS 1, 2, and 3

Background

Hammond Units 1, 2, and 3 are identical 115 MWg Babcock & Wilcox (B&W) sub-critical boilers that went into service in the 1950's. The key design features of these units are provided in Table 1. A side cross section of the units is shown in Figure 2. Southern Company test crews conducted baseline emissions and boiler performance tests in June 2000.

Table 1 Hammond Units 1, 2, and 3 unit configuration

Unit rating:	115 MWg
Main steam flow @ MCR:	725,000 lb/hr
Reheat steam flow @ MCR:	650,000 lb/hr
Design steam temperature superheat/reheat:	1005°F / 1005°F
Furnace draft:	balanced
Furnace dimensions:	34 ft wide x 21 ft deep
Burner firing arrangement:	front wall, 4 wide x 4 high
Pulverizers:	4 B&W EL
Burner capacity @ peak load (122% MCR):	72 MMBtu/hr

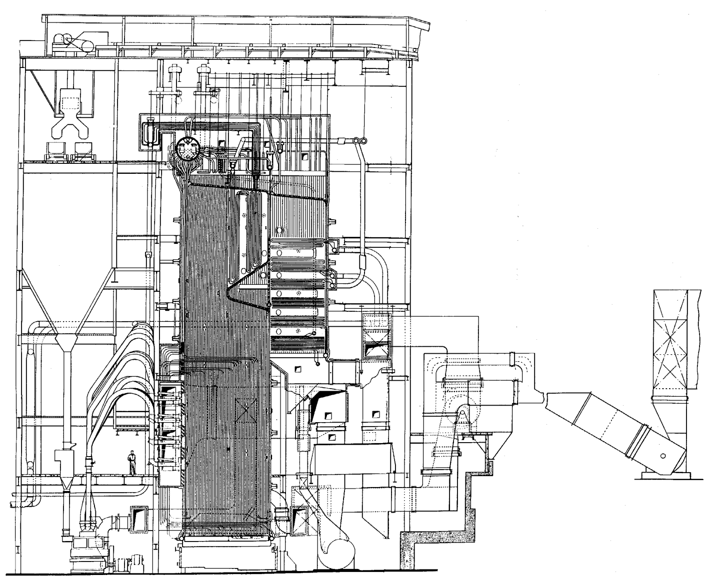


Figure 2 Hammond units 1, 2, and 3 schematic

Retrofit Goals and Scope

RPI was contracted in December 2000 to retrofit Hammond Unit 2 followed by Units 1 and 3. The retrofit goals were to reduce NO_X to $\leq$ 0.38 lb/MMBtu with acceptable levels of CO and unburned carbon (UBC) in the fly ash while maintaining acceptable boiler performance. The design coal analysis is provided in Table 2. The major equipment in RPI's retrofit package included:

- Sixteen low NO_X CCV® Dual Air Zone burners with venturi nozzle, low swirl coal spreader and flame stabilizer ring,
- Sixteen new retractable class I oil ignitors, and
- Thirty-two new flame scanners.

Table 2 Design coal analysis (as received basis), Hammond units

Proximate (wt %)		Ultimate (wt %)	
Fixed Carbon	54.74	Carbon	75.49
Volatile	32.38	Hydrogen	4.50
Moisture	5.45	Nitrogen	1.39
Ash	7.43	Oxygen	4.62
		Sulfur	0.77
FC/VM Ratio	1.53	Moisture	5.45
HHV (Btu/lb)	13,364	Ash	7.43

Hammond Unit 2 Post-retrofit Experience and Burner Performance Test Results

The unit outage occurred during the fall of 2001 with initial operation beginning in December 2001. Optimization tests scheduled for January 2002 were interrupted for an eight-week turbine outage. In April 2002 RPI and Southern Company test crews completed the unit optimization and acceptance testing. Additional system problems were encountered during the burner commissioning period. These additional system problems stem from the Distributed Control System (DCS) retrofit, ignitor control system problems, scanner setup problems, turbine vibration, and questions about the primary air flow measurement issues.

During the initial optimization in January 2002, the unit demonstrated difficulty maintaining scannable and stable coal flames at 33% unit load with only two mills in service. During the eight-week turbine outage RPI and Southern Company analyzed the most recent mill and unit data to determine the cause of the low load flame stability problems. CFD modeling results suggested that primary air to coal ratios greater than 3.0 could produce detached flames. In April 2002 following the turbine outage, mill primary air characterization tests were conducted to confirm whether or not excessive primary air to coal ratio was the root cause as initially surmised. Mill 2D was found to have a higher actual primary air flow than indicated in the control room. The higher air flow caused the air to coal ratio to exceed the design limits of the new burners. The air flow curves were adjusted in the DCS for Mill 2D so that the DCS values matched the actual as measured values.

Subsequent low load tests at 33% MCR again resulted in detached coal flames and also pulverizer trips. Following additional investigation using the IBAM™ probes and CFD model, it was determined that the flame stability problems resulted from inadequate air flow through the in service burners. In service burner air flow was masked by a combination of backend in-leakage and excessive air flow through out of service burners. Burner air shroud opening on out of service burners was reduced, and unit excess air level was increased resulting in well-attached and stable coal flames. After adjustment of the mill and correction to the unit air flow at low load was completed, optimization testing was resumed.

Substantial air mal-distribution was discovered in the burner windbox as evidenced by CO spikes measured at the economizer outlet gas-sampling grid. Burner air shrouds were biased as necessary and peak CO levels were reduced from 3000+ ppm to 60 ppm. Full load tests were conducted at various TA swirl settings to confirm the CFD modeling results. Only four of sixteen burners required settings slightly different than the CFD modeling predicted.

Acceptance tests were conducted at three boiler load points as contractually mandated. A comparison of baseline, guarantee, and post-retrofit data for NO_X and fly ash UBC is provided in Figures 3 and 4. As the data indicate, the NO_X levels were consistently lower than the guarantee of 0.38 lb/MMBtu at all loads. The actual NO_X attained was approximately 0.36 lb/MMBtu, which represents some of the lowest NO_X emissions for a "burners only" approach on this type of boiler firing eastern bituminous coal. Typical CO emissions ranged between 30 to 39 ppm for the entire load range tested.

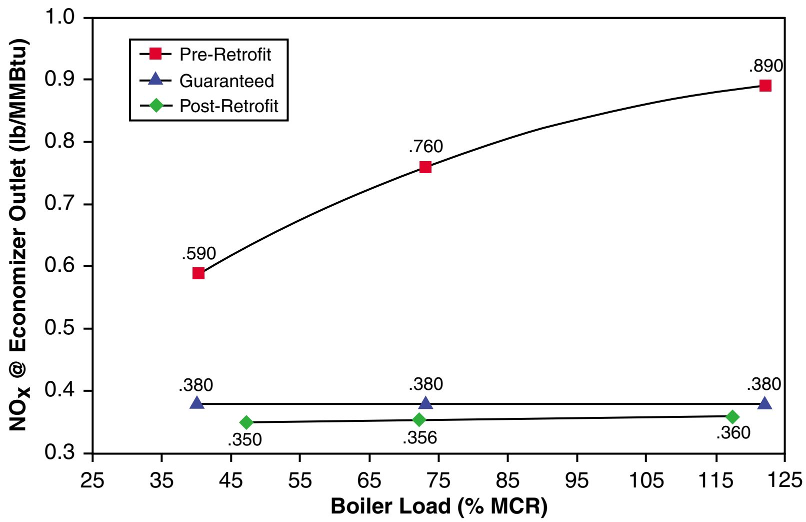


Figure 3 Comparison of pre-retrofit, guaranteed, and post-retrofit NO_X emissions

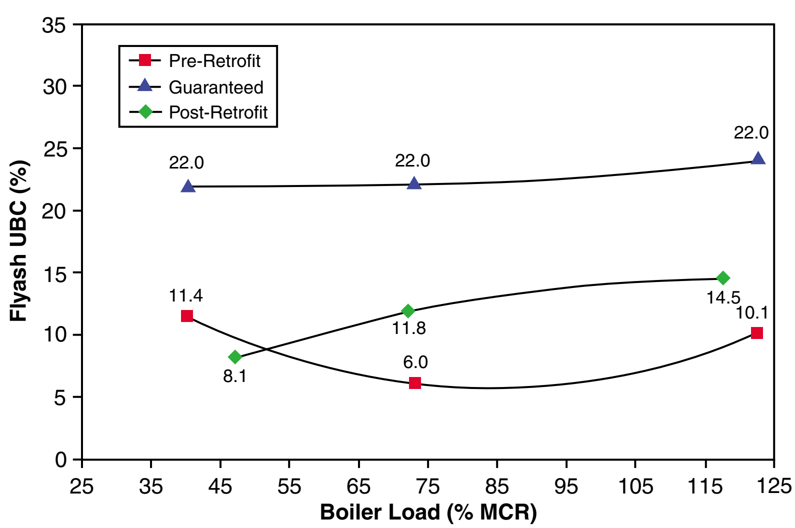


Figure 4 Comparison of pre-retrofit, guaranteed, and post-retrofit flyash UBC

In addition to these measurable guarantees, the Dual Air Zone CCV® burners retrofitted on this unit were able to maintain stable, attached flames with a flame length that fit into a relatively shallow furnace depth of 21 feet. Typically for a shallow furnace and a burner heat input of 72 MMBtu/hr the flame length is a concern because of water wall wastage due to flame impingement. The RPI patented low NO_X coal burner design makes it possible to control the flame length on relatively shallow units. The flame length was also carefully analyzed during the design phase. A RPI calculation method is used in conjunction with the spreader angle selection. These calculations were compared to the furnace depth to verify the flames would not impinge on the rear wall.

Hammond Units 1 and 3 were retrofitted with identical equipment and restarted in October and December 2002, respectively. Test result for Unit 1 was very similar to the results on Unit 2 with all emissions and performance guarantees being met. Commissioning time was approximately 10 days for Unit 1. At the time of writing, performance testing on Unit 3 is currently in progress.

BRANCH UNITS 3 and 4

Background

Georgia Power Harllee Branch Units 3 and 4 are 535 MWg, supercritical Babcock & Wilcox cell fired boilers that went into initial operation in the late 1960's. The key design features of these units are provided in Table 3. A side cross section of the units is shown in Figure 5. Southern Company test crews conducted baseline emissions and boiler performance tests in the spring of 2000.

Table 3 Branch 3 and 4 unit configurations

Unit rating:	535 MWg
Main steam flow @ MCR:	3,569,700 lb/hr
Reheat steam flow @ MCR:	3,057,900 lb/hr
Design steam temperature superheat/reheat:	1000°F / 1000°F
Furnace draft:	balanced draft
Furnace dimensions:	54 ft wide x 42 ft deep
Burner firing arrangement:	(20) 2-high cell opposed wall, 5 wide x 2 high
Pulverizers:	(10) B&W EL-76
Burner capacity @ peak load (103% MCR):	116 MMBtu/hr

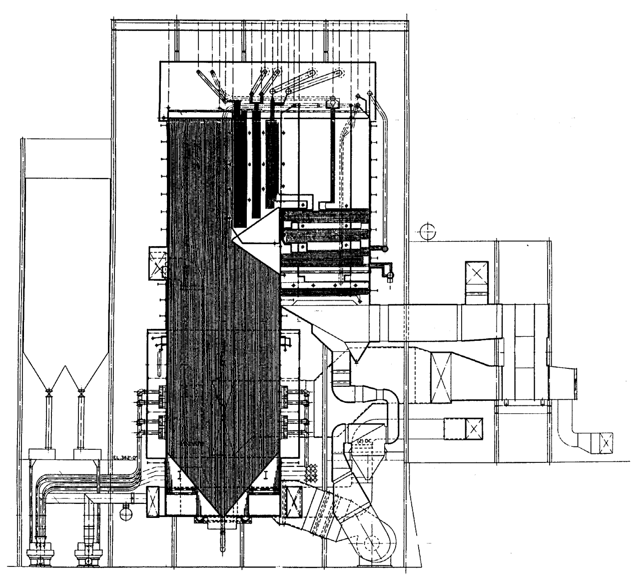


Figure 5 Branch Units 3 and 4 schematic

Retrofit Goals and Scope

RPI was contracted in July 2001 to retrofit Branch Units 3 and 4 starting with Unit 4 and followed by Unit 3. The major low NO_X retrofit project goals established by Georgia Power were to lower NO_X to $\leq$ 0.45 lb/MMBtu with acceptable levels for CO and fly ash unburned carbon, while maintaining acceptable boiler performance. The design coal analysis is shown in Table 4. The major retrofit equipment for each unit included the following:

- Forty low NO_X Dual Air Zone CCV® burners with venturi nozzle, low swirl coal spreader and flame stabilizer ring,
- Forty new retractable, class I, oil fired ignitors mounted in the secondary air annulus of each burner, and
- Forty new flame scanners.

Table 4 Design coal analysis (as received basis), Branch units

Proximate (wt %)		Ultimate (wt %)	
Fixed Carbon	50.57	Carbon	71.09
Volatile	34.38	Hydrogen	4.73
Moisture	6.00	Nitrogen	1.59
Ash	9.00	Oxygen	6.23
		Sulfur	1.31
FC/VM Ratio	1.47	Moisture	6.00
AFT (°F)	2,622	Ash	9.00
HHV (Btu/lb)	12,550		

RPI's retrofit solution consisted of a "burners only" approach. Overfire air (OFA) ports, as proposed by other low NO_X burner suppliers, were not utilized to preclude staged combustion and the subsequent concern for lower furnace corrosion. The existing cell burner configuration was also retained without the need to re-space the burners into a typical wall fired arrangement. CFD modeling by the ignitor vendor demonstrated the need for individual ignitors for each burner due to the inherent differences in flame shape between the low NO_X Dual Air Zone CCV® burner with low swirl coal spreader and the original B&W cell burner with diverging impeller.

CFD aerodynamic modeling was used to determine the initial Dual Air Zone CCV® burner register settings for SA/TA flow split and TA swirl as discussed in the "Single Burner CFD Modeling" section of this paper.

Branch 4 Burner Performance Test Results

Unit 4 was restarted the last week of February 2002 following a six-week outage. Pre-optimization tests were conducted to balance oxygen levels across the economizer outlet gas sampling grid using the burner air shrouds. A total of four optimization tests were conducted between March 8 and 11 at the corresponding steam flows for peak, intermediate, and low loads per contract requirements. A single optimization test was conducted on March 22 at full load. Final acceptance tests were conducted on March 27 and 28 by Southern Company test crews and all performance guarantees were demonstrated. A comparison of the baseline, guarantee, and post-retrofit acceptance test results for NO_X, CO, and flyash UBC is provided in Figures 6 through 8.

The only burner adjustments made during optimization testing were individual burner air shroud settings that were biased to balance oxygen and minimize CO at the economizer outlet gas sampling grid. The burner register settings for SA/TA flow split and TA swirl determined by CFD modeling were used throughout the optimization and acceptance tests, thus minimizing the time required for burner optimization and tuning.

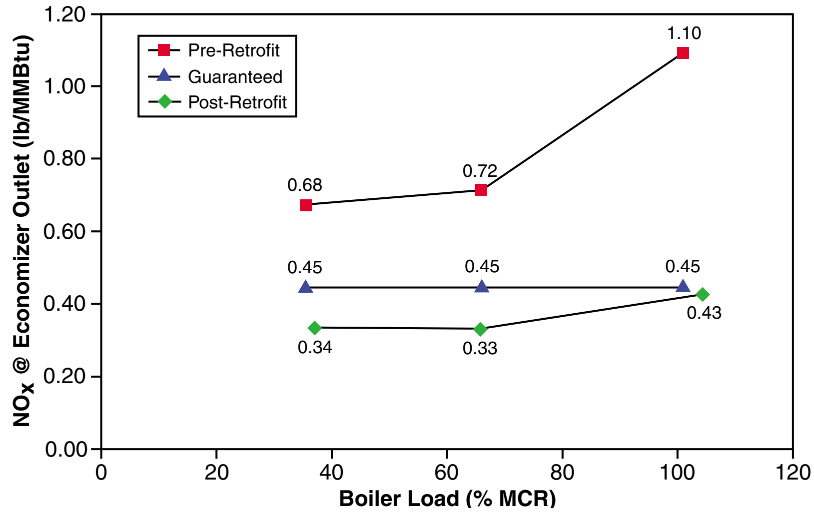


Figure 6 Comparison of pre-retrofit, guarantee, and post-retrofit NO_X

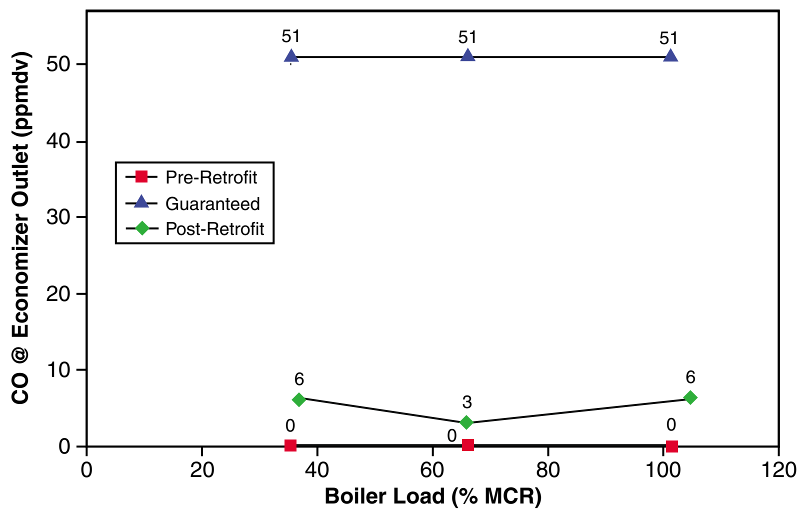


Figure 7 Comparison of pre-retrofit, guarantee, and post-retrofit CO

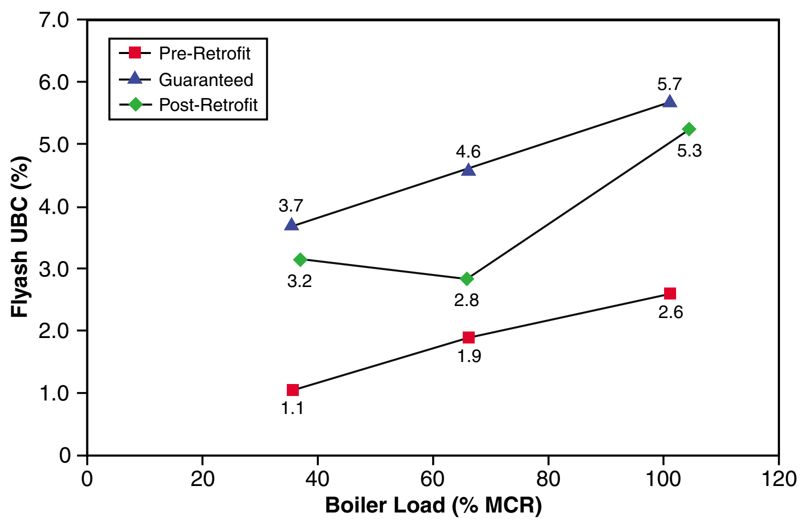


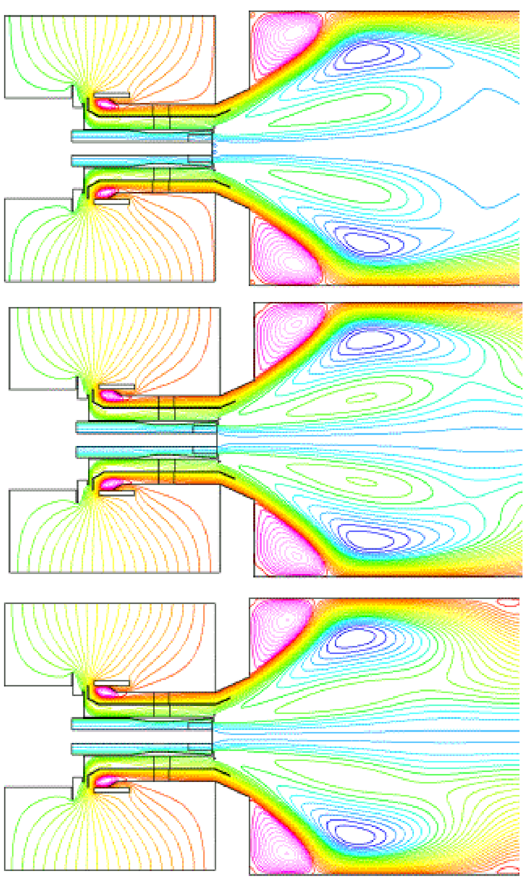
Figure 8 Comparison of pre-retrofit, guarantee, and post-retrofit flyash UBC

At the time of writing, fabrication is complete for the Branch Unit 3 equipment. The outage is currently scheduled to begin March 1, 2003 with a tentative restart the end of April 2003.

SINGLE BURNER CFD MODELING

CFD modeling adds value to the burner design phase of a low NO_X retrofit project. Plug-in low NO_X burner retrofits require proper control settings to meet boiler performance guarantees. Typically in retrofit projects, boiler performance guarantees require maintaining pre-retrofit boiler efficiency, superheat and reheat steam temperatures, and windbox-to-furnace pressure differentials while meeting guarantee NO_X emissions, CO emissions, and flyash UBC values. Simple 2-D single burner CFD models employing only aerodynamics and/or combustion become a cost-effective design tool to predict burner settings necessary to achieve optimum near burner aerodynamics for low NO_X emissions and low UBC as well as estimated changes in flame length and attachment. The CFD results highlight the type and location of the flame structure's internal re-circulation zone (IRZ). Aerodynamic interactions of swirling air flows leaving the burner dominate the control of IRZ characteristics. Near burner aerodynamics relate qualitatively to flame behavior (e.g., flame length and attachment), UBC and NO_X emissions when coupled with full-scale burner combustion test results.

Figure 9 shows the predicted near burner internal re-circulation zone (IRZ) for the Hammond Unit 2 low NO_X Dual Air Zone CCV® coal burner at three different tertiary air (TA) swirl vane settings. The computed stream-lines for low TA swirl angle indicate that two near burner flow re-



TA Vane Angle (Degrees)	UBC (%)	NO_X (lb/MMBtu)
30	7.89	0.397
35	8.48	0.354
40	13.33	0.368

Figure 9 Comparison of CFD predictions of near burner flow behavior and actual burner performance test data of UBC and NO_X emissions for Hammond Unit 2

circulation zones exist: a) an external re-circulation zone (ERZ) driven by secondary air (SA) and b) an IRZ driven partially by primary air (PA). The PA-driven IRZ is essential for establishing a fuel rich zone during the initial combustion process, good flame attachment, and low flyash UBC. Figure 9 indicates that the PA-driven IRZ diminishes as TA swirl vane angle increases, resulting in less coal particle capture by the IRZ and increased flyash UBC levels. To the right of the CFD results in Figure 9 are actual burner optimization test data on flyash UBC and NO_X emissions recorded at Hammond Unit 2. The test data agree well with the indications in the CFD predictions, i.e., UBC is the lowest for a strong PA-driven IRZ at low TA angles while flyash UBC sharply increases as the PA-driven IRZ disappears at high TA angles.

The effect of internal air staging on near burner aerodynamics is also studied using CFD. Figure 10 shows the predicted near burner aerodynamics over a range of SA/TA flow rate ratio. The near burner aerodynamics change as the SA/TA flow rate ratio is increased from cases (a) to (d) in Figure 10. The cases shown in Figures 11b and 11c provided optimum burner settings for NO_X and flyash UBC at Hammond Unit 2.

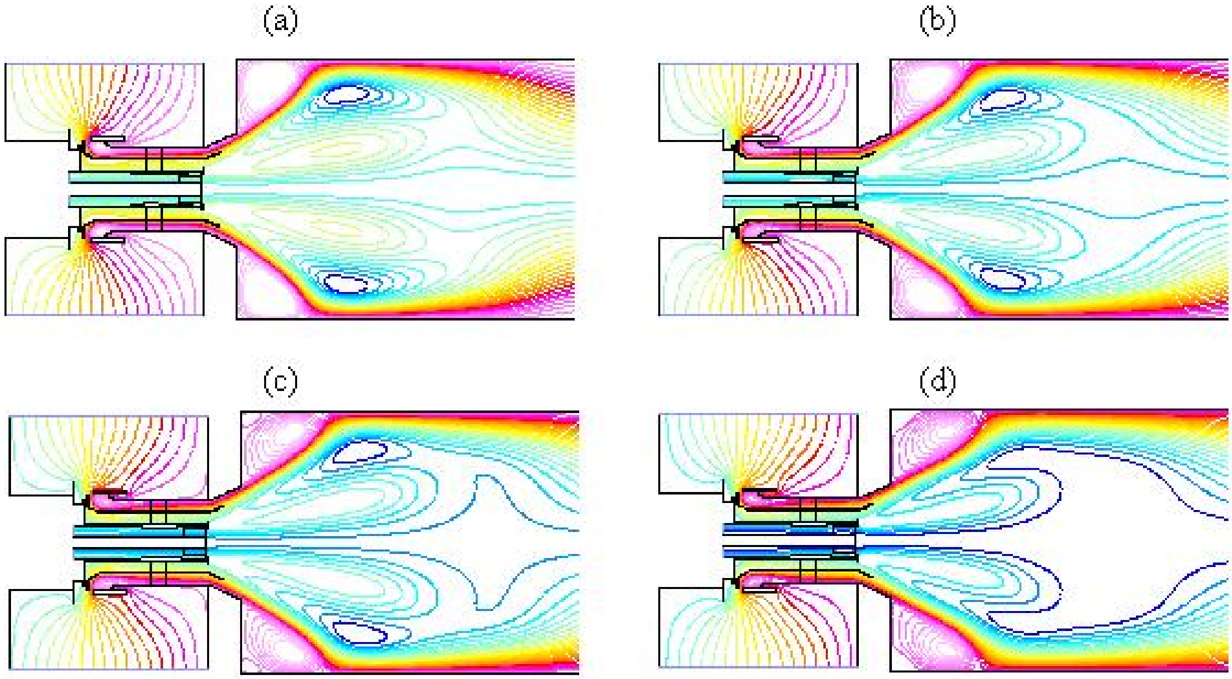


Figure 10 Effect of SA/TA flow rate ratio on near burner aerodynamics at Hammond Unit 2 (SA/TA ratio= (a) 0.72x, (b) 0.90x, (c) x, and (d) 1.15x, x being the optimum setting for NO_X and flyash UBC)

Figure 11 compares CFD predicted and actual low NO_X coal flames produced by the cell burners at Branch Unit 4. The CFD flame predictions, i.e., temperature contours, compare favorably with observed flame attachment, shape, and length. For low NO_X emissions in a cell-fired burner arrangement, achieving a narrow coal flame with little flame interaction is critical for achieving low NO_X emissions. As predicted by CFD modeling and shown in Figure 11, the coal flames do not interact and thus low NO_X is achieved. The pulverized coal fineness level at Branch Unit 4 was below desired levels on 200 Mesh. The average coal fineness was 98.9 % through 50 Mesh, 82.7% through 100 Mesh, and 51% through 200 Mesh. Due to substandard pulverized coal fineness level at Branch 4, the CFD predictions showed a slight flame detachment at the burner discharge.

CFD modeling can also be used to predict burner settings to achieve optimum near burner aerodynamics. These predictions expedite low NO_X burner tuning efforts and boiler commissioning in both new boiler and burner retrofit projects. Table 5 compares burner settings and performance from CFD-derived recommendations and field test results for Hammond Unit 2 and Branch Unit 4 CCV® Dual Air Zone low NO_X coal burner retrofit projects. The field test results are final burner settings for the performance guarantee tests at peak unit loads.

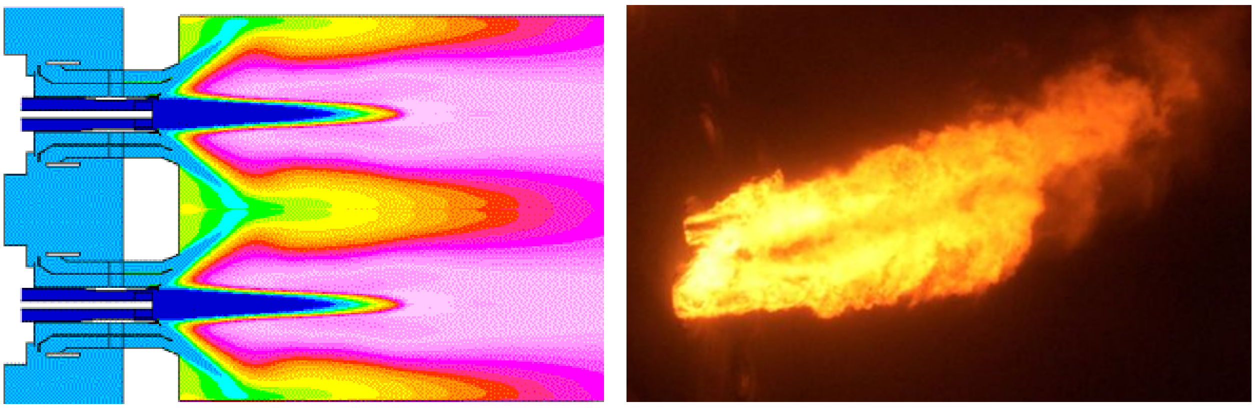


Figure 11 Comparison of CFD predicted and observed flame conditions at Branch Unit 4 (CFD results indicate predicted temperature contour)

Table 5 Comparison of CFD-recommended burner settings and finalized burner settings from peak load guarantee testing

Furnace Type	**Front Wall-Fired Subcritical (Hammond Unit 2)**		**Cell-Fired Supercritical (Branch Unit 4)**	
Number of Burners	16		40	
Data Source	CFD Results	Accept Test	CFD Results	Accept Test
SA Damper opening (in.)	1.25	1.25	1.75	1.88
Avg. Burner Shroud Position (% open)	60	50	60	67
TA Vane Angle (°)	30-35	35	30	30
PA Coal Spreader Setback (in.)	1	1	1	1
dP Windbox-Furnace (iwc)	4.50	4.57	4.00	4.10
Avg. SA/TA Flow Ratio	x	1.16x	y	0.92y
Optimization Test Duration (Days)	--	14	--	2

CONCLUSIONS

The latest RPI Dual Air Zone CCV® burner design is capable of achieving NO_X reductions in excess of 60% from uncontrolled levels using a "burners only" approach. These NO_X reductions are achieved with minimal impact to CO emissions and flyash UBC as demonstrated at Hammond Units 1, 2, and 3 and Branch Unit 4. The cell-fired configuration is deemed by the industry as a potentially difficult low NO_X retrofit application due to the very high burner zone heat release rates and close burner spacing. The ability to achieve substantial NO_X reduction on cell fired units like Branch Unit 4 without OFA or the need for burner re-spacing has been demonstrated using RPI's patented low NO_X Dual Air Zone CCV® burner technology.

The low NO_X retrofit projects with Southern Company demonstrated that CFD modeling of Dual Air Zone CCV® burner aerodynamics greatly reduced burner setting and tuning time prior to the guarantee acceptance tests. The two projects met all the performance guarantees with minimal burner tuning efforts (a 50% reduction in testing and setup time). In these cases the economic value of CFD is obvious and very real. CFD predictions of burner settings for startup can trim two to three weeks off burner tuning duration and boiler commissioning. Not only do start-up and commissioning costs go down many thousands of dollars, but the unit also produces full power and revenue during what would normally have been a relatively long period for tuning and testing.

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